Clock and LO Components in 5G Base Stations – Performance Parameters and Test Solutions

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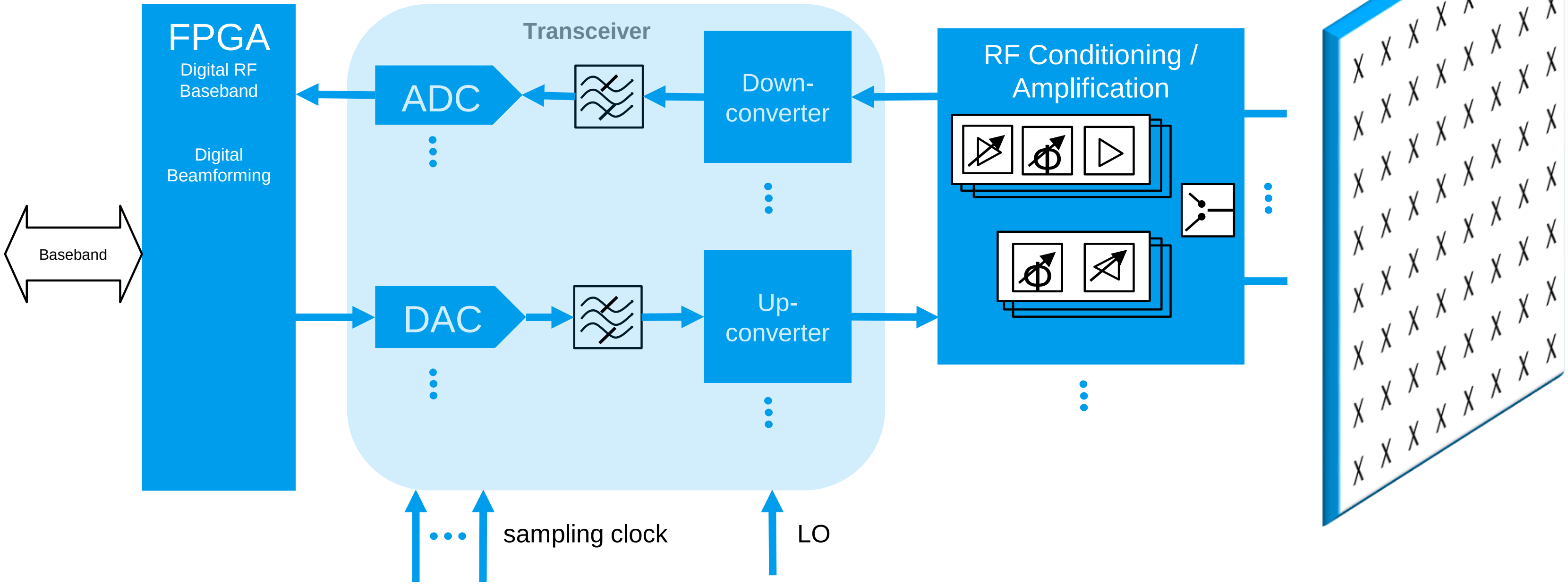
ROHDE&SCHWARZ

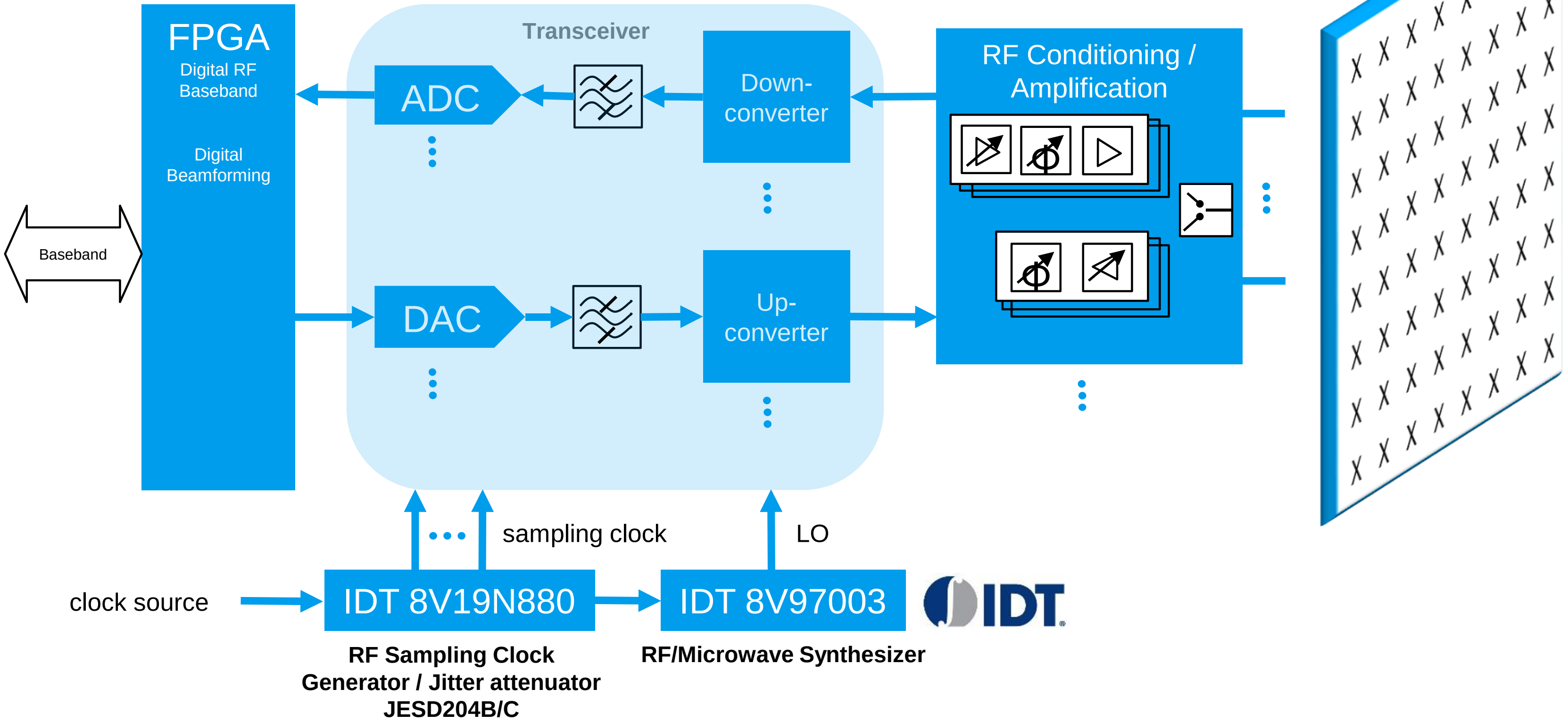
5G Base Station Architecture

Sampling clock and LO signals



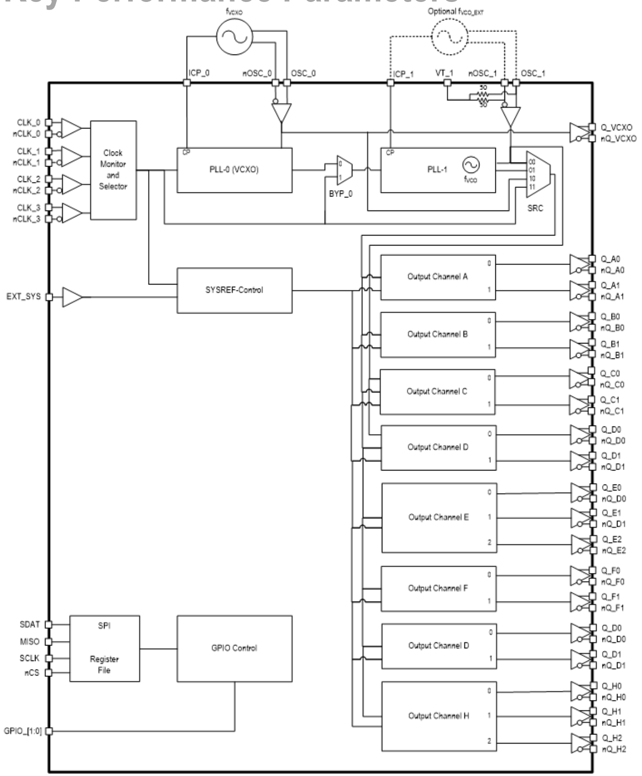
5G Base Station Architecture

IDT 8V19N880 (sampling clock) and IDT 8V97003 (LO)



8V19N880 Clock Generator / Jitter Attenuator

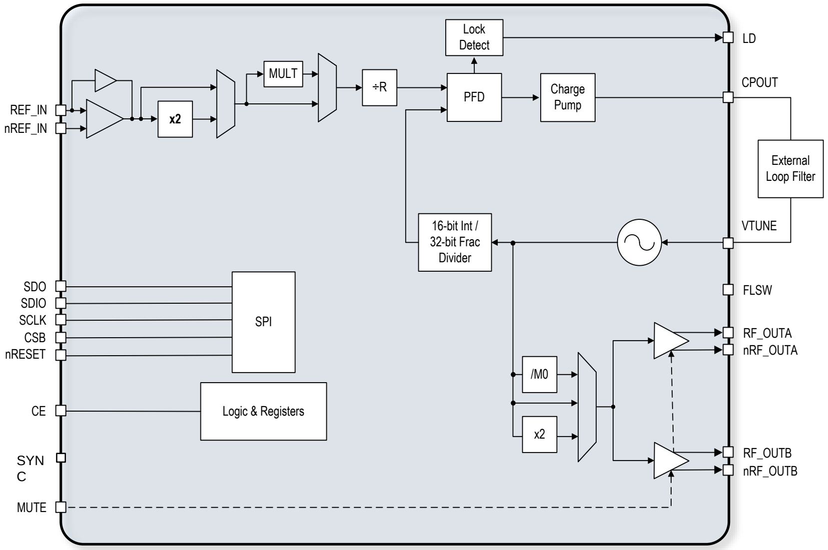
Key Performance Parameters



- Jitter attenuation of reference clock
- Generates sampling clock of ADC/DAC/transceiver components
- Designed and optimized for:
  - Low phase noise and spurious
  - Frequency generation up to 4GHz
  - JESD204B/C: SYSREF generation and phase management
- Dual PLL loop
  - PLL-0: jitter attenuation
  - PLL-1: frequency generation
- High fanout and low clock skew
  - 18 outputs (clock and SYSREF)

8V97003 18GHz Microwave Synthesizer

Key Performance Parameters



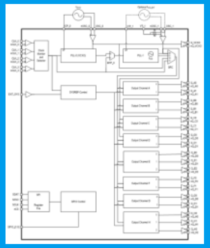
- RF range: 187.5 to 18,000 MHz
- Generates a high-performance reference frequency for up/down converters
- Wideband integrated VCO allows for wide and continuous output frequency range
- RMS jitter (20kHz -100 MHz) at 6GHz: -60dBc
- High output power for best output signal integrity and simplifies layout at high frequencies
- Very low skew drift contributes to reduction of radio path calibration events in beamforming applications
- +95C ambient / +105C case temperature

Sampling Clock and LO Sources for 5G Base Stations

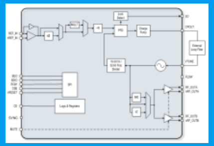
Key Performance Parameters and Relevance

Key Performance Parameters	8V19N880	8V97003
Output Power	-	✓
Phase Noise Performance	✓	✓
Spur Suppression	✓	✓
Jitter Attenuation	✓	-
Delay Adjustment	✓	-
Timing Alignment	✓	✓
Clock Input Monitoring, Holdover and Relocking	✓	-

IDT 8V19N880



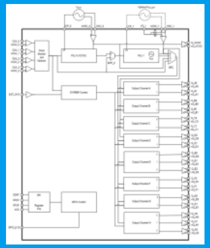
IDT 8V97003



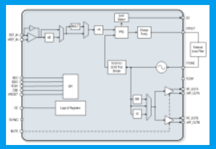
Sampling Clock and LO Sources for 5G Base Stations

Key Performance Parameters	8V19N880	8V97003
Output Power	-	✓
Phase Noise Performance	✓	✓
Spur Suppression	✓	✓
Jitter Attenuation	✓	-
Delay Adjustment	✓	-
Timing Alignment	✓	✓
Clock Input Monitoring, Holdover and Relocking	✓	-

IDT 8V19N880

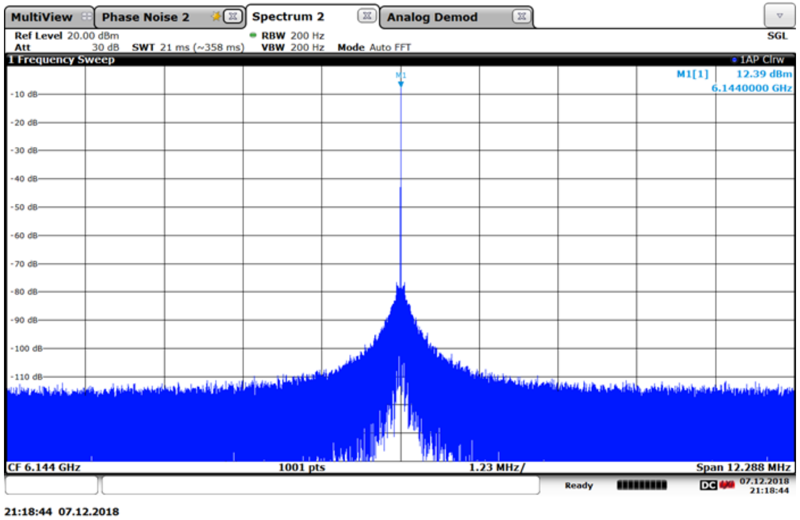


IDT 8V97003

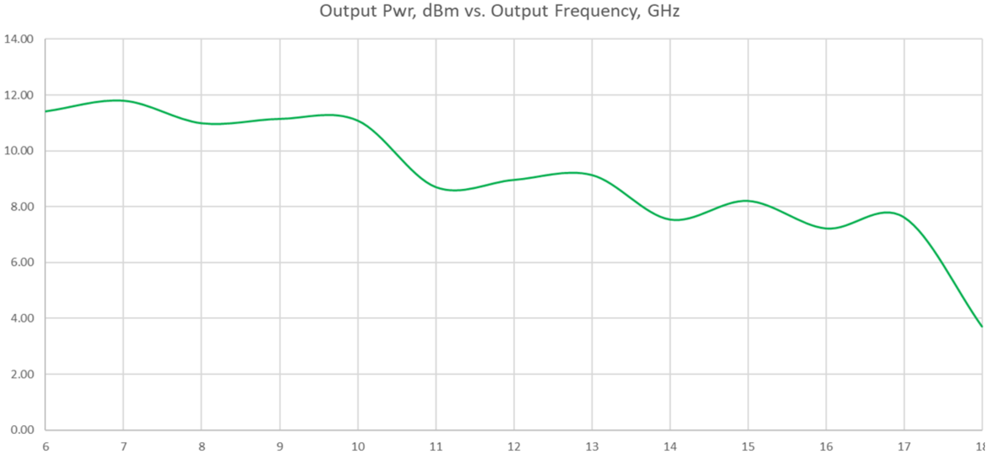


Microwave Synthesizer Output Power versus Frequency

Measured: 6.144GHz, 12.39dBm

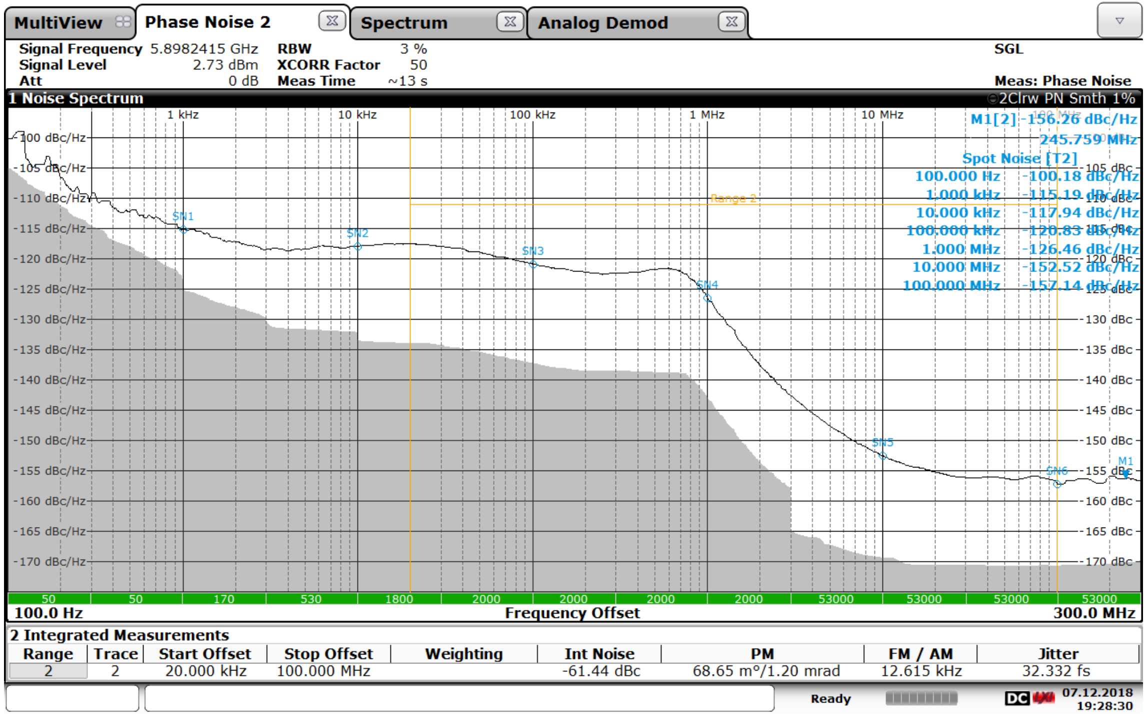


Typical*



*NOTE: Inductively loaded terminations, single-ended; double terminated load

Microwave Synthesizer Phase Noise



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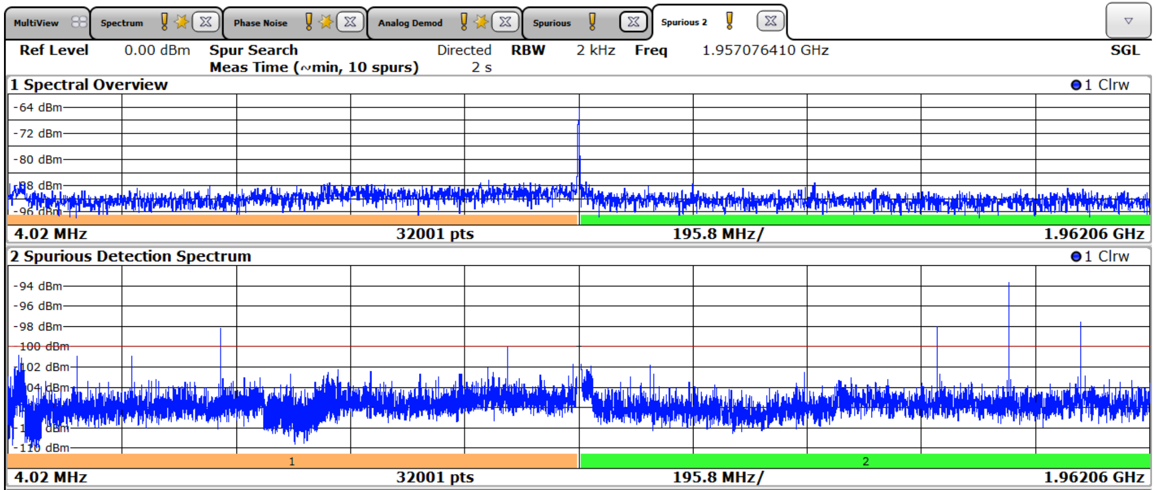
- 5.9GHz, 32fs (-61dBc)
- PLL integer mode

IDT 8V19N880 Spurious Suppression

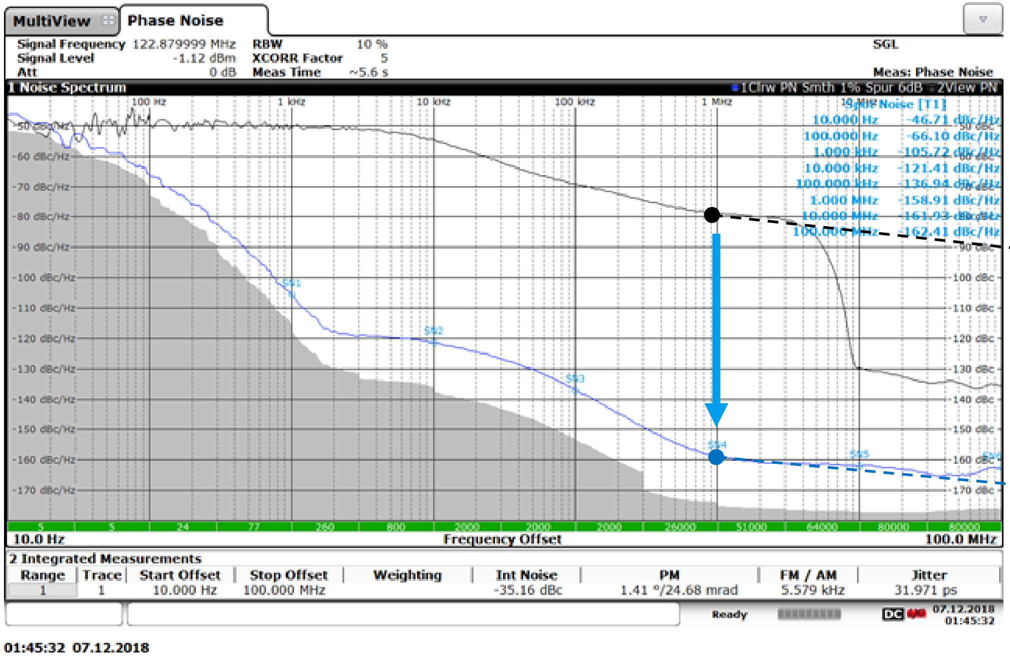


3 Spurious Detection Table

Frequency	Power	RBW	Segment Start	Segment Stop	Spur ID
-614.288144 MHz	-98.23 dBm	1.598 kHz	61.147973 MHz	441.801932 MHz	S1
-122.794335 MHz	-99.97 dBm	1.036 kHz	573.746036 MHz	979.020000 MHz	S2
614.371551 MHz	-98.01 dBm	1.735 kHz	1.423832276 GHz	1.962060000 GHz	S3
737.131032 MHz	-93.69 dBm	1.735 kHz	1.423832276 GHz	1.962060000 GHz	S4
860.220512 MHz	-97.57 dBm	1.735 kHz	1.423832276 GHz	1.962060000 GHz	S5

- 8V19N880 983.04MHz clock output
- Measurement span: >0Hz to 2x $f_{carrier}$
- Spurious attenuated to <-93dBm
  - At 737.31MHz from carrier
- Improves data converter characteristics

RF Sampling Clock 8V19N880 Jitter Attenuation



Plot 1

- PLL input (noisy)
- -90dBc/Hz (1MHz offset)

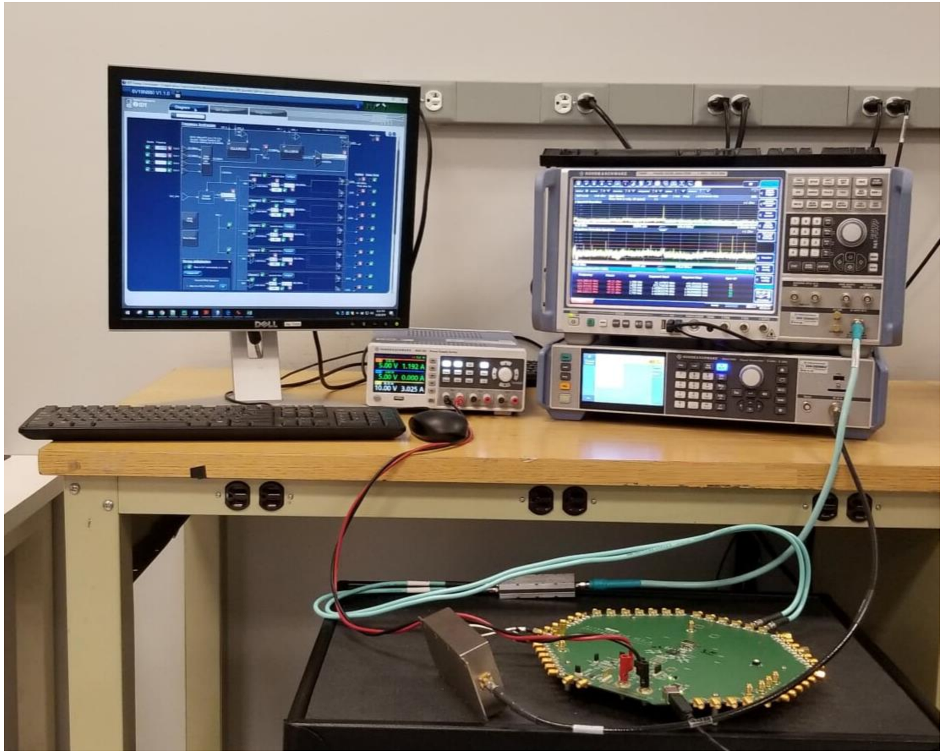
Plot 2

- PLL output (clean)
- -159dBc/Hz (1MHz offset)

- Attenuation -69dB

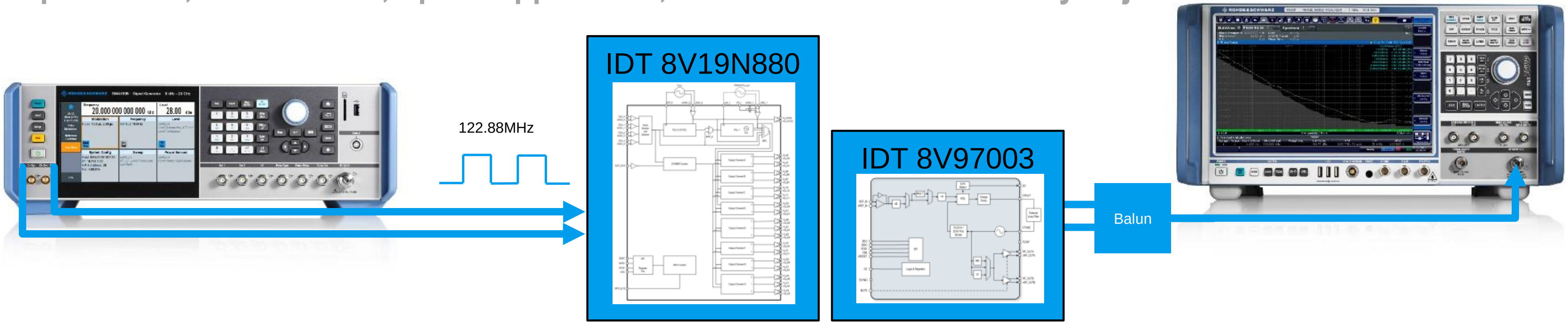
Measurement Setup

Output Power, Phase Noise, Spur Suppression, Jitter Attenuation and Delay Adjustment



Measurement Setup

Output Power, Phase Noise, Spur Suppression, Jitter Attenuation and Delay Adjustment



R&S SMA100B
- 8kHz to 3 / 6 / 12.75 / 20GHz (further MW models planned)
- options for high and ultra high output power
- superior spectral purity:
  - ultra-low phase noise and wideband noise with several performance options
  - low harmonics, subharmonics and nonharmonics
- analog modulation (option):
  - AM, PM, FM
- additional clock synthesizer (option): 3 / 6GHz
  - single-ended or differential output
  - sine-wave or square wave signal

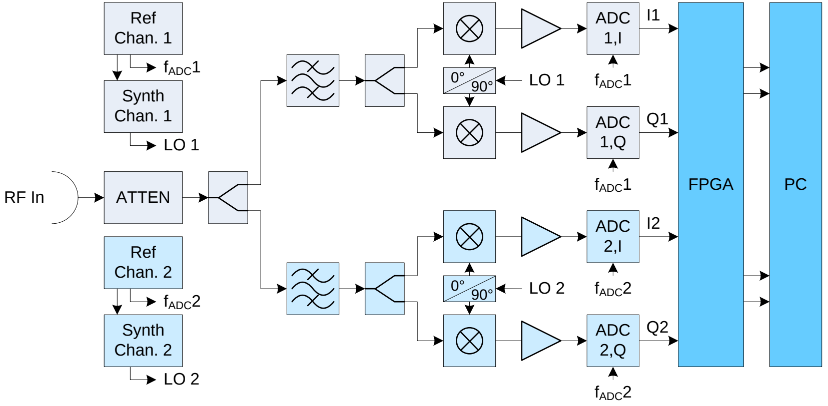
R&S FSWP
- 1MHz to 8GHz, 26.5GHz, 50GHz
- high phase noise sensitivity
- options to further improve phase noise sensitivity by cross-correlation
- built-in spectrum analyzer (option)
- options for signal demodulation
  - e.g. analog demodulation: AM, FM, PM
- built-in low phase noise signal source and additive phase noise method (option)

Phase Noise Measurement in R&S FSWP

Digital Demodulation and Cross Correlation

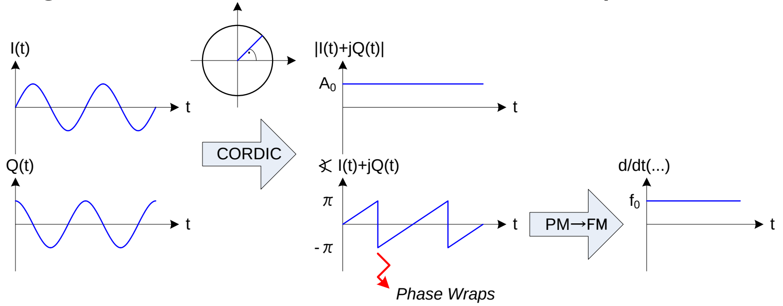
FSWP Architecture

- Signal Path

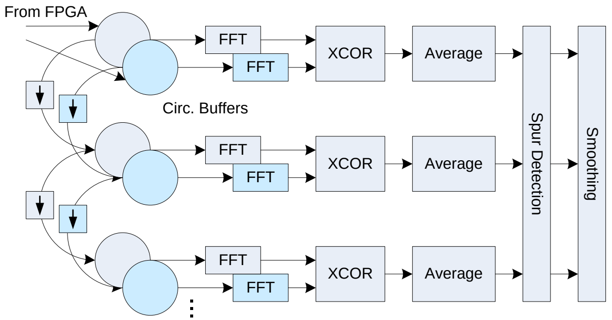


FSWP Signal Processing

- Digital Demodulation: PN and AN in parallel

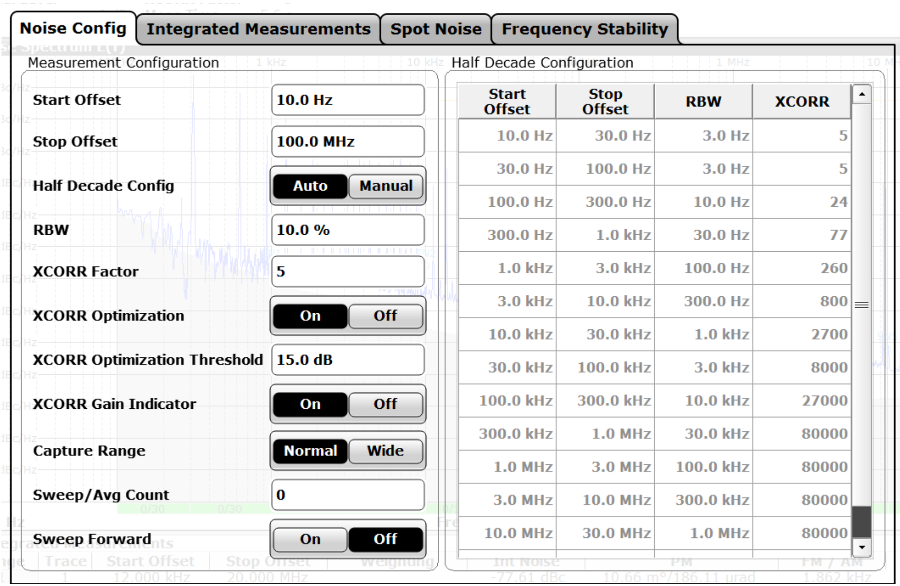


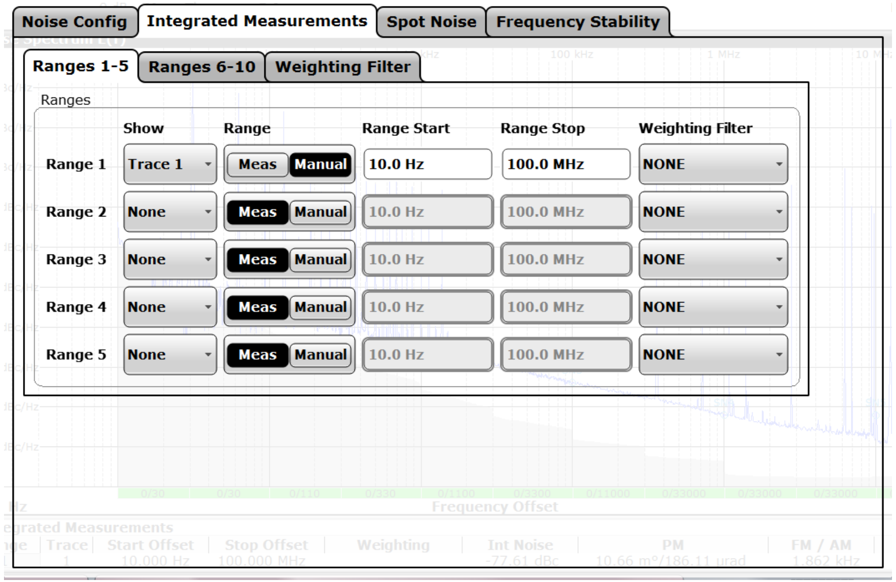
- Cross-Correlation



Phase Noise Measurement in R&S FSWP

Configuration of Phase Noise Measurement and Jitter Integration





Spur Suppression Measurement in R&S FSWP

Optimized Spur Measurement with best fit RBW

- Challenge:
  - spur measurements are time consuming
  - RBW needs to be set for
    → required frequency resolution
    → required noise level

- Basic Spur Measurement: manual RBW setting
  - range table with manual RBW setting in each range

- Optimized Spur Measurement: automatic RBW setting
  - range table with spur parameters in each range
  - instrument calculates optimizes RBW settings
  - huge speed improvements

Spurious Emissions

	Range 1	Range 2	Range 3	Range 4
Range Start	9 kHz	150 kHz	30 MHz	1 GHz
Range Stop	150 kHz	30 MHz	1 GHz	12.75 GHz
Filter Type	Normal(3dB)	Normal(3dB)	Normal(3dB)	Normal(3dB)
RBW	1 kHz	10 kHz	100 kHz	1 MHz
VBW	3 kHz	30 kHz	300 kHz	3 MHz
Sweep Time Mode	Auto	Auto	Auto	Auto
Sweep Time	14.1 ms	29.9 ms	32.1 ms	35.3 ms
Detector	RMS	RMS	RMS	RMS
Ref Level	-10 dBm	-10 dBm	-10 dBm	-10 dBm
RF Att Mode	Auto	Auto	Auto	Auto
RF Attenuation	0 dB	0 dB	0 dB	0 dB
Preamp	Off	Off	Off	Off
Sweep Points	701	4001	32001	32001
Stop After Sweep				
Transducer	None	None	None	None
Limit Check	Absolute	Absolute	Absolute	Absolute
Abs Limit Start	-30 dBm	-30 dBm	-30 dBm	-30 dBm
Abs Limit Stop	-30 dBm	-30 dBm	-30 dBm	-30 dBm

Insert before Range | Insert after Range | Delete Range | Adjust X-Axis

	Range 1	Range 2	Range 3	Range 4
Range Start	30 MHz	5.75 GHz	6.25 GHz	13 GHz
Range Stop	5.75 GHz	6.25 GHz	13 GHz	26 GHz
Spur Detection Threshold Start	-120 dBm	-30 dBm	-120 dBm	-100 dBm
Spur Detection Threshold Stop	-120 dBm	-30 dBm	-120 dBm	-100 dBm
Limit Offset to Detection Threshold	0 dB	0 dB	0 dB	0 dB
Peak Excursion	3 dB	3 dB	3 dB	3 dB
Minimum Spur SNR	10 dB	10 dB	10 dB	10 dB
Maximum Final RBW	100 kHz	100 kHz	100 kHz	100 kHz
Auto RBW	On	On	On	On
RBW	Auto	Auto	Auto	Auto
Number of FFT Averages	2	2	2	2
Ref Level	0 dBm	0 dBm	0 dBm	0 dBm
RF Attenuation	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off

Spur Suppression Measurement in R&S FSWP

Measurement Process: Optimized Spur Measurement

Spectral overview & noise floor estimation	Spur detection	Spot search
• initial sweep with large RBW • estimation of noise floor to determine optimum RBWs • Sub-segmentation of ranges with best fit RBWs	• second sweep with calculated best fit RBWs • spur detection • generation of preliminary spur table	• final sweep on preliminary spur table with RBW to also meet spur SNR • pass/ fail analysis • generation of final spur table (updated spur frequencies and level, detection of noise artefacts and residual spurs)

Spur Suppression Measurement in R&S FSWP

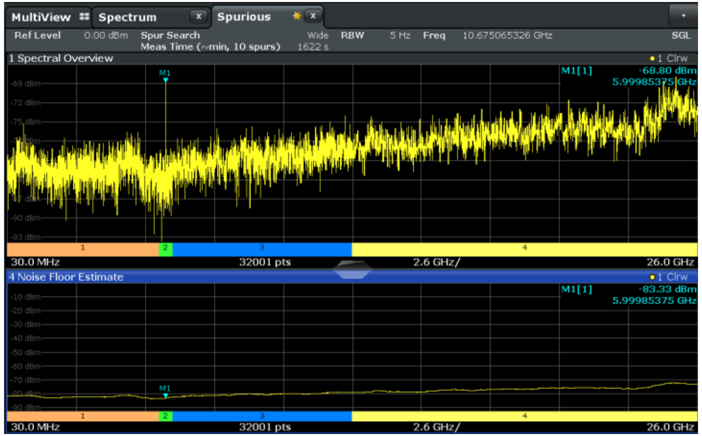
Optimized Spur Measurement: wide search settings

- ✓ User needs to define only the frequency ranges and the maximum allowed spurious level.
- ✓ Main settings are predefined but can be changed if required (for example 10 dB S/N margin)
- ✓ Optimum RBW is calculated by the application

	Range 1	Range 2	Range 3	Range 4
Range Start	30 MHz	5.75 GHz	6.25 GHz	13 GHz
Range Stop	5.75 GHz	6.25 GHz	13 GHz	26 GHz
Spur Detection Threshold Start	-120 dBm	-30 dBm	-120 dBm	-100 dBm
Spur Detection Threshold Stop	-120 dBm	-30 dBm	-120 dBm	-100 dBm
Limit Offset to Detection Threshold	0 dB	0 dB	0 dB	0 dB
Peak Excursion	3 dB	3 dB	3 dB	3 dB
Minimum Spur SNR	10 dB	10 dB	10 dB	10 dB
Maximum Final RBW	100 kHz	100 kHz	100 kHz	100 kHz
Auto RBW	On	On	On	On
RBW	Auto	Auto	Auto	Auto
Number of FFT Averages	2	2	2	2
Ref Level	0 dBm	0 dBm	0 dBm	0 dBm
RF Attenuation	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off

Spur Suppression Measurement in R&S FSWP

Optimized Spur Measurement: Sweep 1 - Spectral overview & noise floor estimation



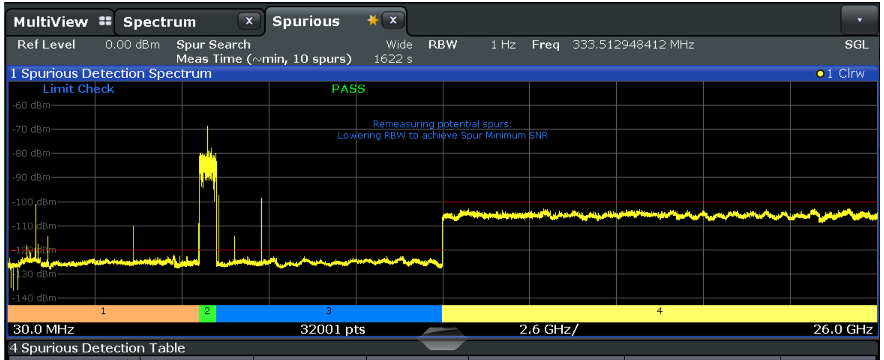
- ✓ Measures noise floor for user settings
- ✓ Estimates required measurement time
- ✓ Calculates optimum RBWs for each frequency according to the spurious detection threshold

Segment Table | **Spur Table**

Range	(1) 30 MHz … 5.75 GHz				(2) 5.75 GHz … 6.25 GHz	(3) 6. … 13
Segment Start	30 MHz	1.378772513 GHz	4.203111665 GHz	4.970216126 GHz	5.75 GHz	6.25 G
Segment Stop	1.378772513 GHz	4.203111665 GHz	4.970216126 GHz	5.75 GHz	6.25 GHz	8.05 G
RBW	8 Hz	8.9 Hz	7.3 Hz	10.9 Hz	790.083 kHz	7.6 Hz
Ref Level	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm
RF Attenuation	10 dB	10 dB	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off	Off	Off

Spur Suppression Measurement in R&S FSWP

Optimized Spur Measurement: Sweep 2 – Spur Detection



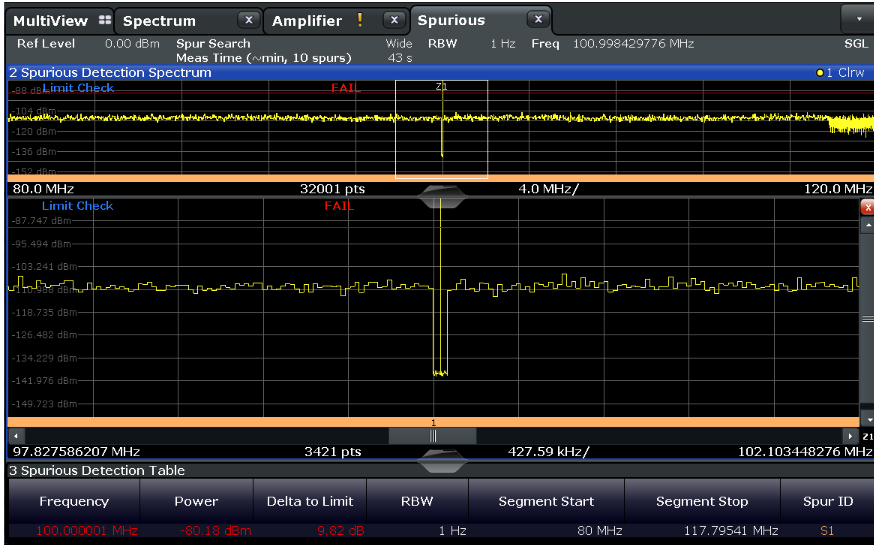
Frequency	Power	Delta to Limit	RBW	Segment Start	Segment Stop	Spur ID
840.421253 MHz	-119.33 dBm	0.67 dB	8 Hz	30 MHz	1.378772513 GHz	S1
869.364869 MHz	-101.19 dBm	18.81 dB	8 Hz	30 MHz	1.378772513 GHz	S2
933.867785 MHz	-117.71 dBm	2.29 dB	8 Hz	30 MHz	1.378772513 GHz	S3
1.206764737 GHz	-114.40 dBm	5.60 dB	8 Hz	30 MHz	1.378772513 GHz	S4
3.766733084 GHz	-110.11 dBm	9.89 dB	8.9 Hz	1.378772513 GHz	4.203111665 GHz	S5
5.713664271 GHz	-109.14 dBm	10.86 dB	10.9 Hz	4.970216126 GHz	5.75 GHz	S6
6.329460454 GHz	-97.41 dBm	22.59 dB	7.6 Hz	6.25 GHz	8.05 GHz	S7
6.801808706 GHz	-114.44 dBm	5.56 dB	7.6 Hz	6.25 GHz	8.05 GHz	S8
7.609656652 GHz	-98.66 dBm	21.34 dB	7.6 Hz	6.25 GHz	8.05 GHz	S9

- ✓ Uses RBW settings calculated in previous sweep
- ✓ Preliminary spur table is the result

Spectral overview & noise floor estimation → **Spur detection** → Spot search

Spur Suppression Measurement in R&S FSWP

Optimized Spur Measurement: Sweep 3 – Spot search



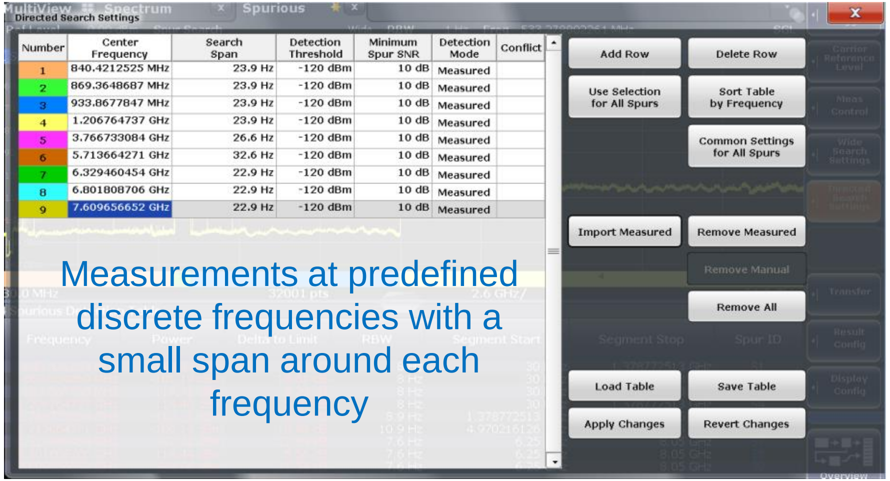
- ✓ Performed over very narrow spans around each spur detected in the previous step
- ✓ Pass/ Fail considering spurious emissions limit and SNR
- ✓ Final spurious table
- ✓ Detects and/or eliminates residual spurs
- ✓ RBW optimized if needed

Spectral overview & noise floor estimation → Spur detection → **Spot search**

Spur Suppression Measurement in R&S FSWP

Optimized Spur Measurement: Directed search at predefined frequencies

- ✓ Recommended if frequencies are known beforehand, like harmonic frequencies
- ✓ Same measurement process as for wide search, but:
  - ✓ Saves measurement time
  - ✓ More precise results, if using a larger SNR

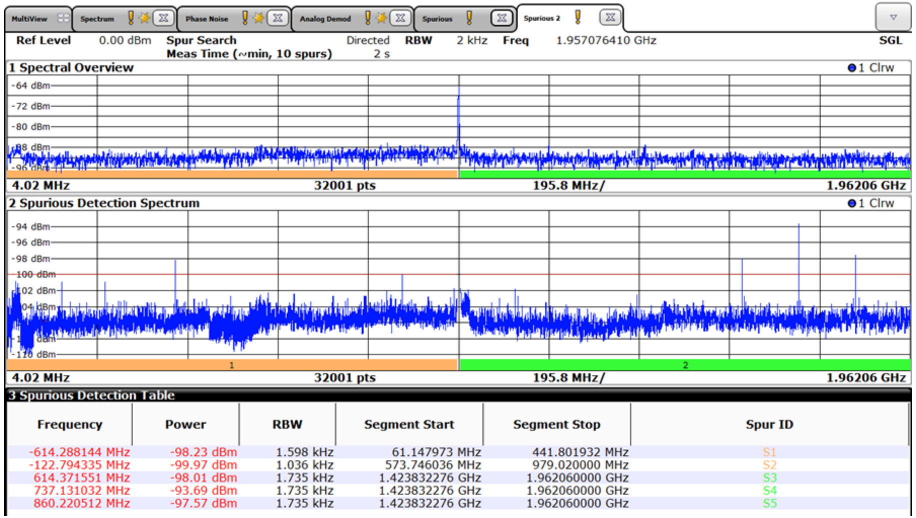


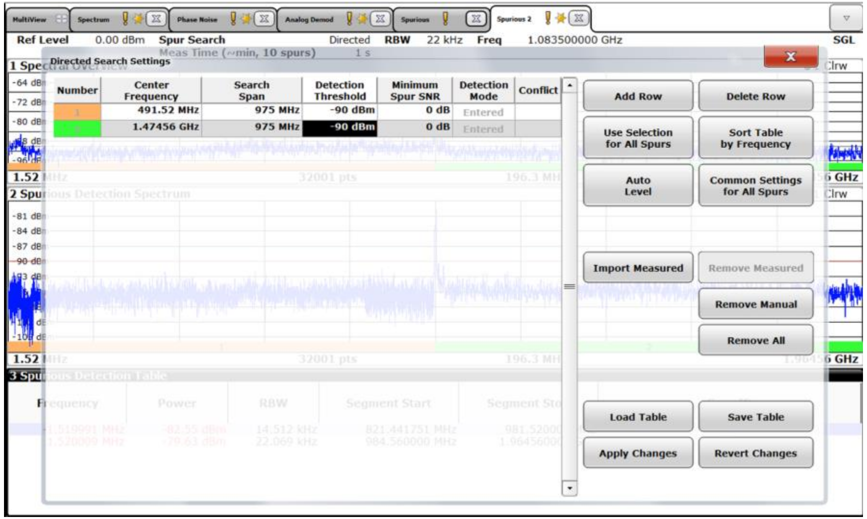
Number	Center Frequency	Search Span	Detection Threshold	Minimum Spur SNR	Detection Mode	Conflict
1	840.4212525 MHz	23.9 Hz	-120 dBm	10 dB	Measured	
2	869.3648687 MHz	23.9 Hz	-120 dBm	10 dB	Measured	
3	933.8677847 MHz	23.9 Hz	-120 dBm	10 dB	Measured	
4	1.206764737 GHz	23.9 Hz	-120 dBm	10 dB	Measured	
5	3.766733084 GHz	26.6 Hz	-120 dBm	10 dB	Measured	
6	5.713664271 GHz	32.6 Hz	-120 dBm	10 dB	Measured	
7	6.329460454 GHz	22.9 Hz	-120 dBm	10 dB	Measured	
8	6.801808706 GHz	22.9 Hz	-120 dBm	10 dB	Measured	
9	7.609656652 GHz	22.9 Hz	-120 dBm	10 dB	Measured	

Measurements at predefined discrete frequencies with a small span around each frequency

Spur Suppression Measurement in R&S FSWP

Range table configuration and measurement result





Jitter Attenuation Measurement w. R&S SMA100B and R&S FSWP

Jitter Transfer Function (JTF)

reference clock
$Jitter_{In}$

f_{In}

PLL1
Jitter
Attenuator

f_{In}

PLL2
Frequency
Synthesizer

f_{Out}

DUT: Clock Generator

bit clock
$Jitter_{Out}$

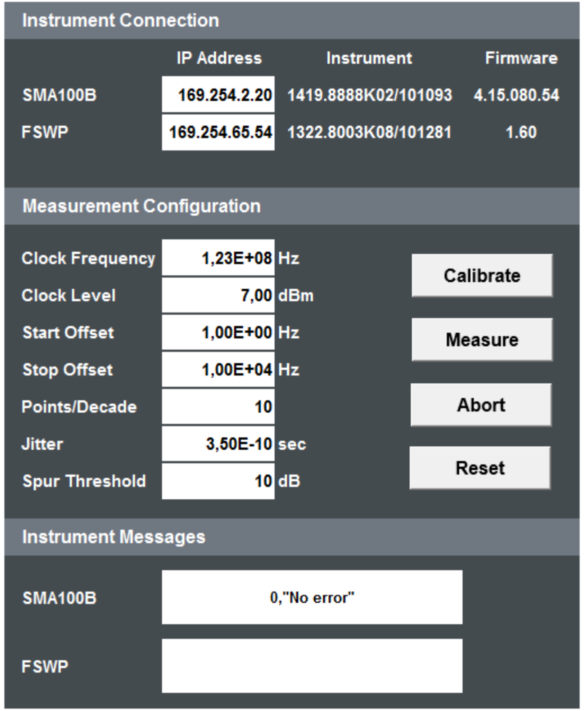
reference clock
with artificial jitter
→ PM modulation

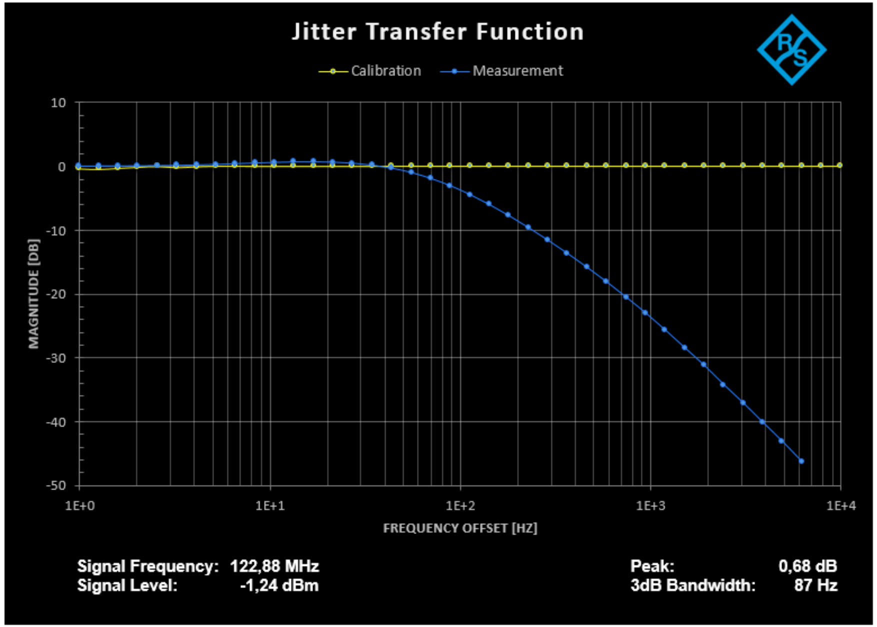
$$JTF = 20 \log \frac{Jitter_{Out}}{Jitter_{In}}$$

Phase noise measurement:
1.) Calibration
2.) Measurement

Jitter Attenuation Measurement w. R&S SMA100B and R&S FSWP

Jitter Transfer Function (JTF): Example

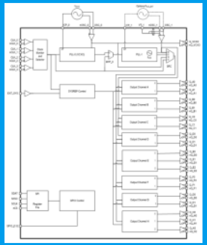




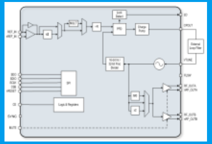
Sampling Clock and LO Sources for 5G Base Stations

Key Performance Parameters	8V19N880	8V97003
Output Power	-	✓
Phase Noise Performance	✓	✓
Spur Suppression	✓	✓
Jitter Attenuation	✓	-
Delay Adjustment	✓	-
Timing Alignment	**✓**	**✓**
Clock Input Monitoring, Holdover and Relocking	✓	-

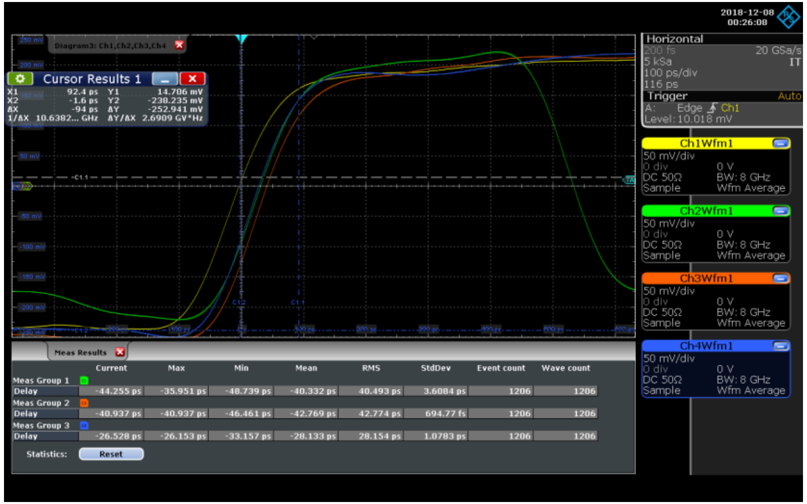
IDT 8V19N880

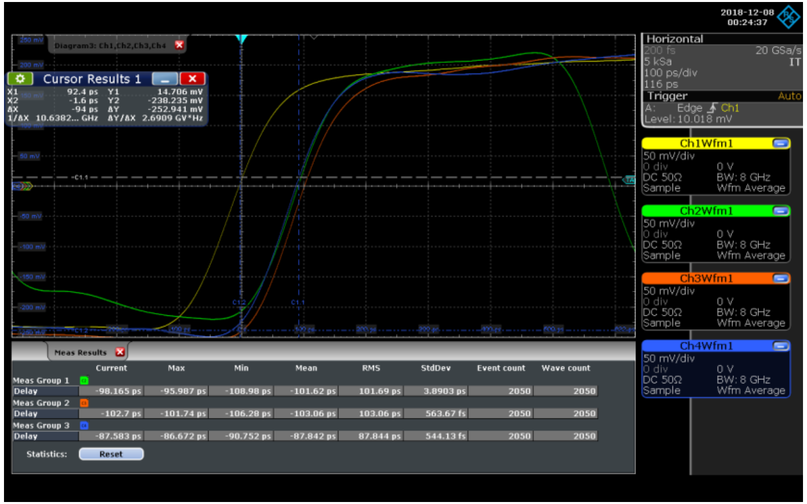


IDT 8V97003



Timing Alignment



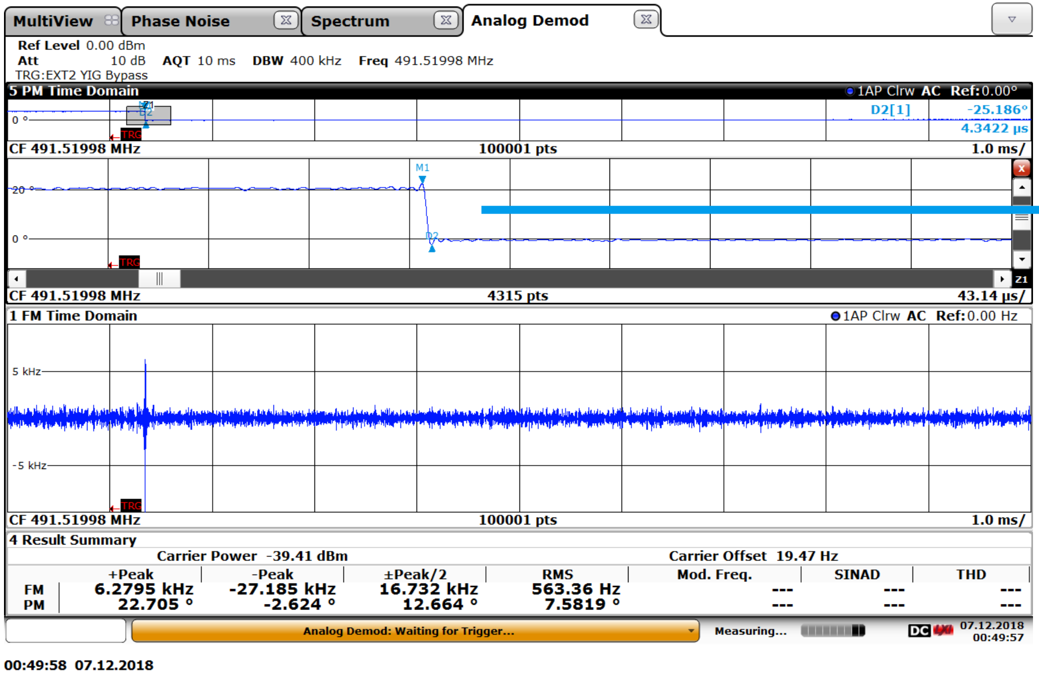


- SYSREF to CLK1-3 alignment
- 42ps

- SYSREF to CLK1-3 alignment
- 103ps

Adjusted by device delay stage in 8V19N880

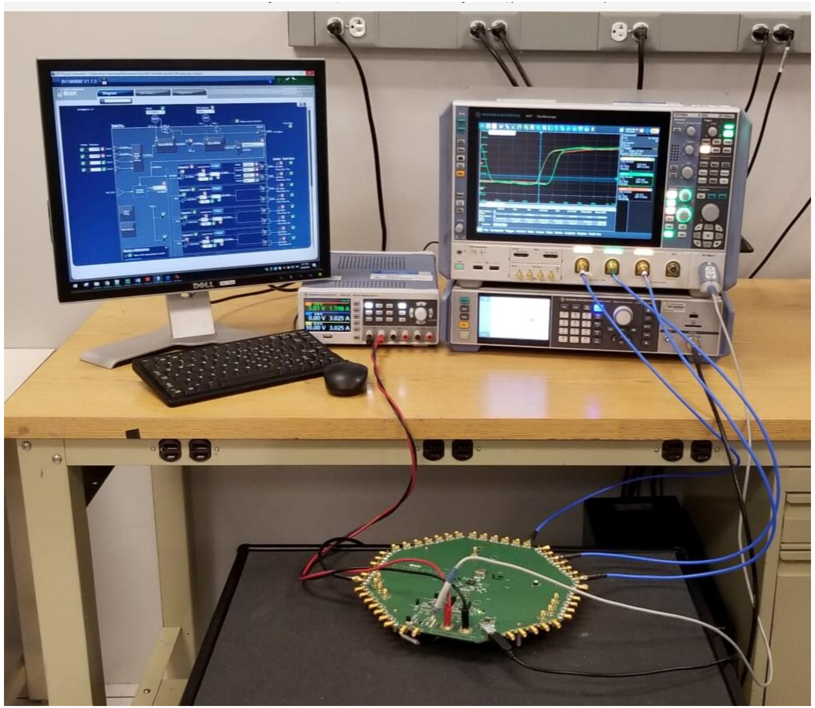
Delay Adjustment / Delay Steps:



(-20°/360°) * 1/491.52MHz = 113ps

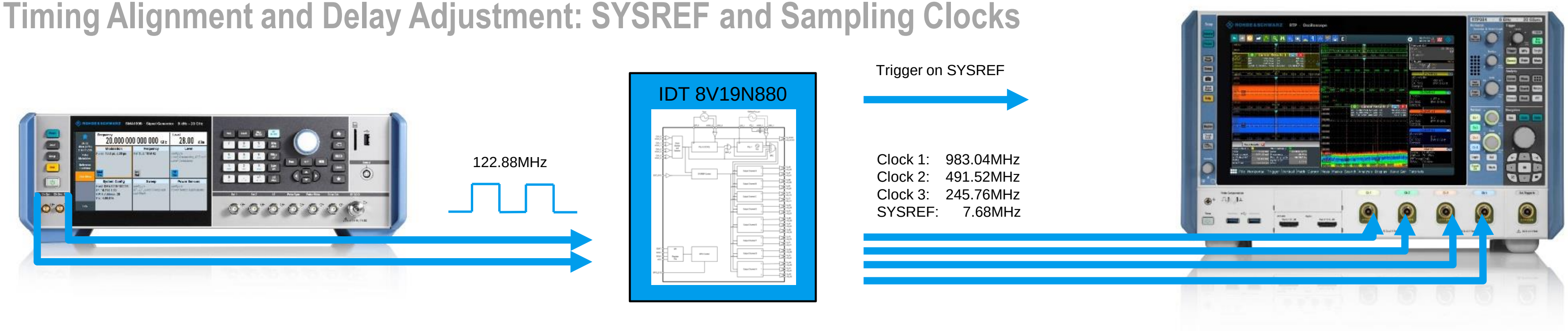
Measurement Setup

Timing Alignment and Delay Adjustment: SYSREF and Sampling Clocks



Measurement Setup

Timing Alignment and Delay Adjustment: SYSREF and Sampling Clocks



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- 8kHz to 3 / 6 / 12.75 / 20GHz (further MW models planned)
- options for high and ultra high output power
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- analog modulation (option):
  - AM, PM, FM
- additional clock synthesizer (option): 3 / 6GHz
  - single-ended or differential output
  - sine-wave or square wave signal

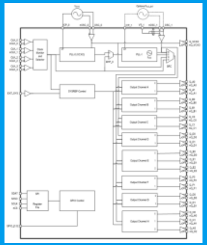
R&S RTP

- available bandwidths: 4 / 6 / 8GHz (further BW models planned)
- channels: 4
- sample rate: 20Gsamples/s
- high-class analog performance
- fastest acquisition rate: 1,000,000 wfms/s
- real-time deembedding
- digital trigger up to full bandwidth
- multi-domain functionality, incl.:
  - digital interface test
  - spectrum and signal analysis
  - power integrity
  - …

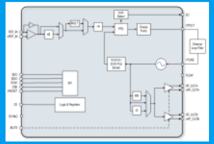
Sampling Clock and LO Sources for 5G Base Stations

Key Performance Parameters	8V19N880	8V97003
Output Power	-	✓
Phase Noise Performance	✓	✓
Spur Suppression	✓	✓
Jitter Attenuation	✓	-
Delay Adjustment	✓	-
Timing Alignment	✓	✓
Clock Input Monitoring, Holdover and Relocking	✓	-

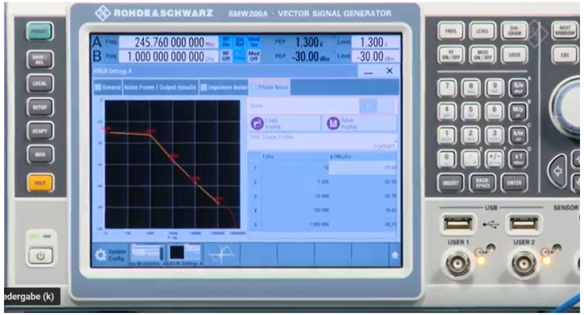
IDT 8V19N880



IDT 8V97003



Clock Input Monitoring, Holdover and Relocking



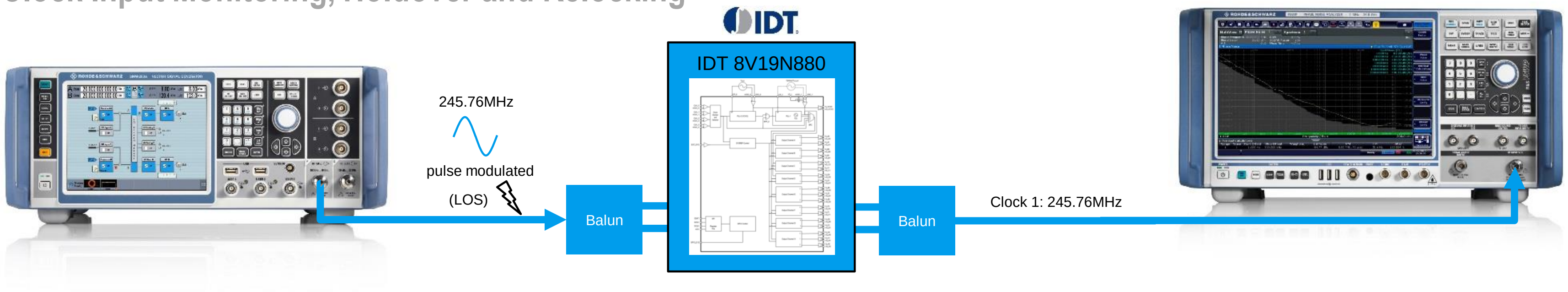
PLL: unlocked re-locking locked

Measurement Setup

Clock Input Monitoring, Holdover and Relocking

Measurement Setup

Clock Input Monitoring, Holdover and Relocking



R&S SMW200A

- 2 RF paths (optional):
  path A: 100kHz to 3 / 6 / 12.75 / 20 / 31.8 / 40GHz
  path B: 100kHz to 3 / 6 / 12.75 / 20GHz
- high signal purity:
  - phase noise, harmonics and spurious
- optional phase noise simulation
  - predefined and user definable phase noise profiles
- analog modulation (options):
  - AM, PM, FM
  - pulse modulator
- digital modulation (options):
  - real-time and ARB based

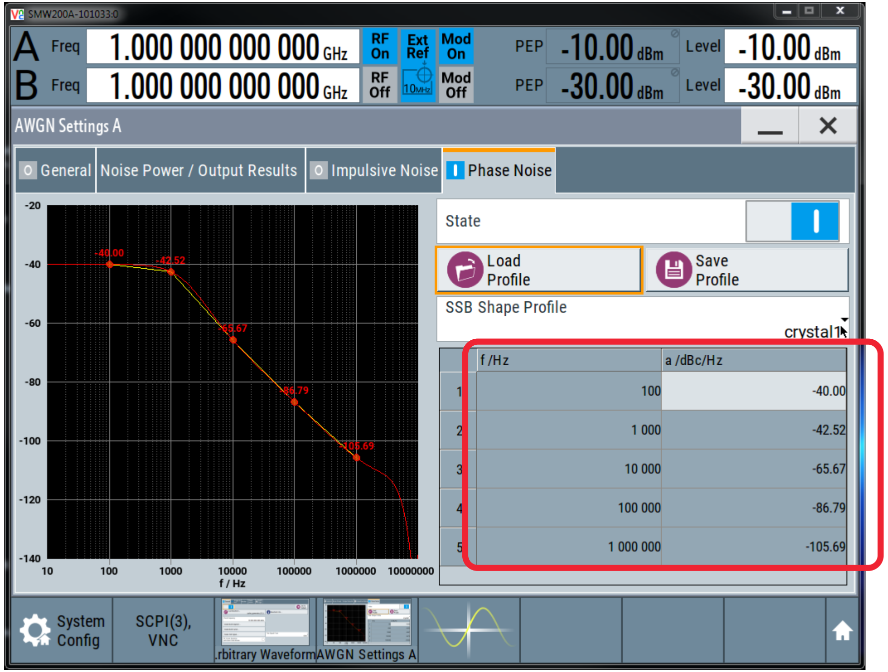
R&S FSWP

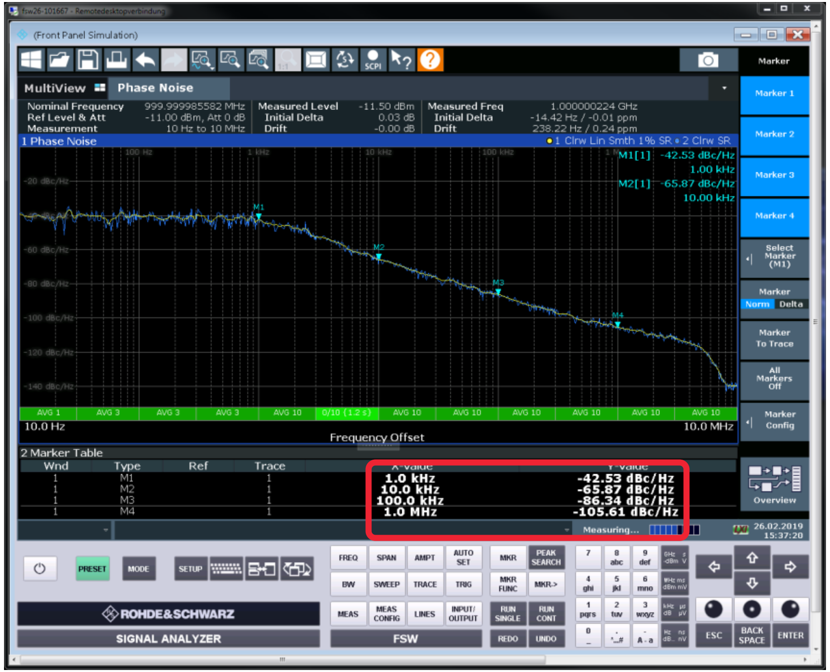
- 1MHz to 8GHz, 26.5GHz, 50GHz
- high phase noise sensitivity
- options to further improve phase noise sensitivity by cross-correlation
- built-in spectrum analyzer (option)
- options for signal demodulation
  - e.g. analog demodulation: AM, FM, PM
- built-in low phase noise signal source and additive phase noise method (option)

Phase Noise Simulation in R&S SMW200A

Example and Measurement Results

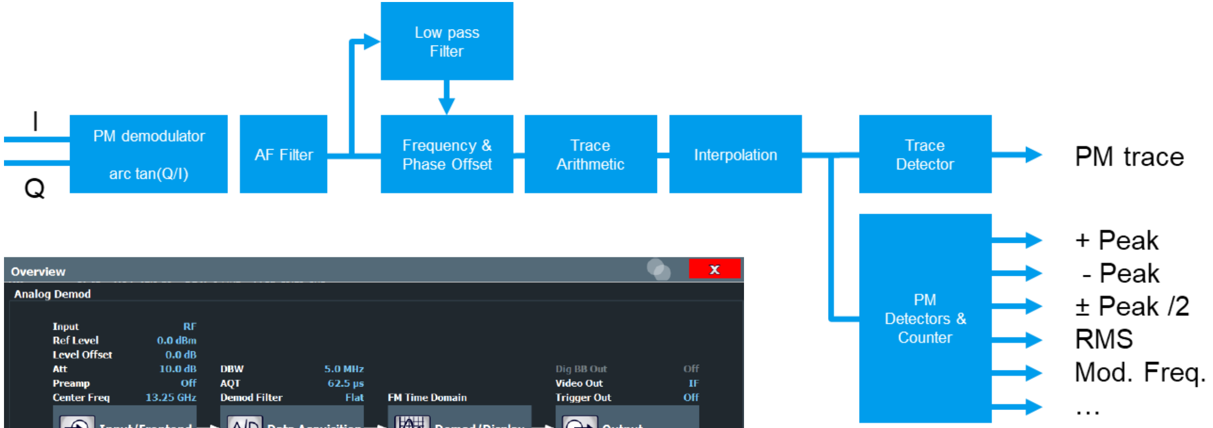
Example: predefined shape crystal1

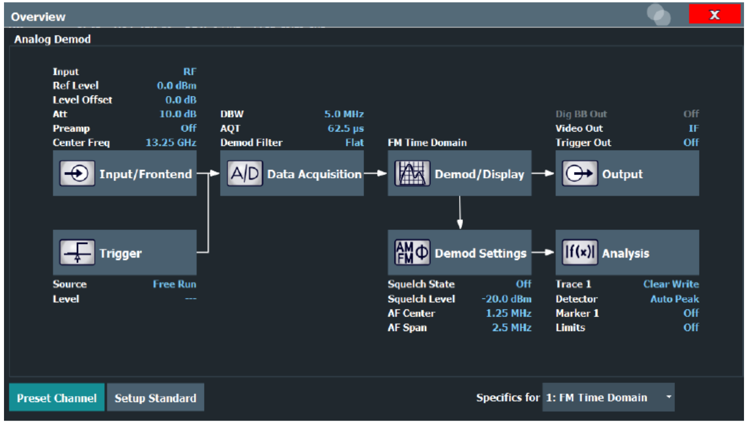


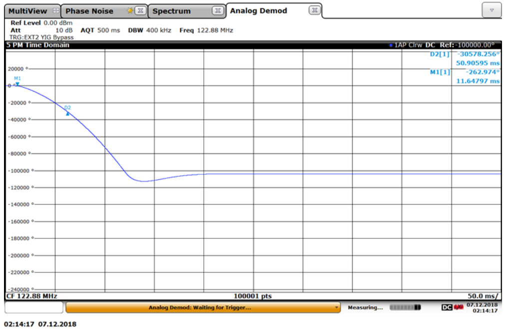


Phase Transient Measurement in R&S FSWP

Configuration of Measurement







Thank You

IDT 8V19N880 (sampling clock) and IDT 8V97003 (LO)

- Low phase noise clock synthesizer and jitter attenuator support best ADC/DAC performance (SNR)
- LO provides sufficient output power for 5G mmWave radio designs – broadband range
- Radio component synchronization per JESD204B/C enabled by flexible clock phase alignment and adjustment capabilities
- Fast and smooth PLL's re-lock behavior in radio clock failure cases
- IDT's RF timing devices meet challenging requirements of 5G radio design

R&S FSWP, R&S RTP, R&S SMA100B, R&S SMW200A

- Accurate and comprehensive performance analysis with R&S FSWP phase noise analyzer (w. optional built-in spectrum and signal analyzer functionality)
  - Phase Noise Performance
  - Output Power and Spur Suppression
  - Jitter attenuation
  - Delay adjustment / Delay Step
  - Phase transients during locked-holdover-relocking cycles
- Precise timing measurements with digital trigger function, using R&S RTP performance real-time oscilloscope
- Stimulation with quasi-ideal or defineable real-world clock signals, using R&S SMA100B or R&S SMW200A

Rohde & Schwarz (China) Technology Co. Ltd.

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